IMPACT OF CABLE BLEEDING TOWARDS CABLE CHARACTERISTICS AND PERFORMANCE IN VDSL2 ANG G.FAST TECHNOLOGIES

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A thesis submitted in
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
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FEBRUARY 2020

To my beloved family

ACKNOWLEDGEMENT

First and foremost, Alhamdulillah thank you Allah for continuous blessing and forgiveness in giving me the strength, ability, patience, and endurance throughout the whole course of the study.

I would like to express my deepest gratitude to my supervisor, Assoc. Prof. Dr. Fauziahanim Che Seman and also to my co-supervisors, Assoc. Prof. Dr. Khairun Nidzam Ramli and Mr. Azhari Asrokin for their priceless guidance, ideas, criticism, knowledge, moral support, time, and many more that could not be listed. Thank you for everything. I have learned in a hard way to not rely on others and believe in yourself.

I would like to convey my sincere thanks to Nurhana Norhan for providing theories and help to process the calculation for maximum achievable bit rate and thanks to copper team for their kind assistance. The same gratitude goes to Telekom Research and Development (R&D), Cyberjaya for giving me an opportunity running experiments by using their facilities during my industrial attachment.

My personal full-hearted thanks also go to my beloved parents Che Ku Alam Bin Che Ku Ali and Naimah Binti Rosnan (*Aboh* and *Ma*) who always give their blessings and prayers for whatever I do in my life. For my awesome siblings many thanks for the encouragement during my research study.

I would also like to deliver my special thanks to all my friends for their constant cheers, providing excellent discussion and for sharing their knowledge as well as giving helpful assistance throughout the progress of the research. I sincerely thank everyone who involved either intentionally or not in completing this thesis.

ABSTRACT

The application of copper cable in broadband services using very high-speed digital subscriber line transceivers 2 (VDSL2) (30a) has been proven to offer up to 50 Mbps upstream (US) and 100 Mbps downstream (DS) bandwidths at lower than 1 km distance. This application has been reckoned as a widely deployed broadband technology, with the latest G.fast technology being integral at present time, which can be attain 1 Gb/s for copper loops up to 250 m. That being mentioned, this project investigated the degradation in performance displayed by copper cable due to cable bleeding, thus contributing towards resistance and capacitance faults, along with varied configurations being simulated and measured. The simulated results were validated based on double-ended measurements performed via Vector Network Analyzer (VNA). A series of comparative studies had been carried out especially for attenuation between ideal and faulty conditions. These attenuation results were extracted to form resistance, capacitance, inductance, and conductance (RLCG) of a transmission line model. For ideal condition in 200 m measurement, the maximum achievable bit rate for VSDL2 was 29 Mbps for US and 79 Mbps for DS, along with estimation speed of G.fast technology in single pair at 662.5 Mbps. The measured and simulated results portrayed exceptional agreement with each other. Due to fault occurrence, the performance of the networks in terms of maximum achievable bit rate and speed performance had degraded. Significant degradation was noted to be the worst for solid cross faults (SCF) and complete open and cross (COC), in comparison to the ideal condition. The COC measurement showed that both US and DS were lower by 38% and 44%, respectively, when compared to those recorded for the ideal case. The general outcomes revealed that small faults had an impact on the performances of network transmission line based on the results of maximum achievable bit rate.

ABSTRAK

Penggunaan kabel tembaga dalam perkhidmatan jalur lebar yang menggunakan VDSL2 (30a) terbukti dapat menawarkan sehingga 50 Mbps hulu dan 100 Mbps hilir data pada jalur lebar yang jaraknya kurang dari 1 km. Penggunaan ini telah dikira digunakan secara meluas dalam teknologi jalur lebar serta teknologi terkini G.fast iaitu keperluan untuk masa kini dimana boleh mencapai 1 Gb/s untuk gelung tembaga sehingga 250 m. Untuk makluman, projek ini menyiasat prestasi penurunan yang ditunjukkan oleh kabel tembaga disebabkan oleh luka kabel yang menyumbangkan kepada kerosakan rintangan dan kerosakan kemuatan disamping dengan pelbagai konfigurasi yang telah disimulasikan dan diukur. Untuk mengesahkan keputusan simulasi tersebut, pengukuran dijalankan dengan menutup dua hujung menggunakan *Vector Network Analyzer* (VNA). Satu siri kajian perbandingan telah dijalankan terutamanya untuk pelemahan diantara keadaan unggul dan keadaan rosak. Keputusan pelemahan ini diekstrak untuk mendapatkan RLCG model talian penghantaran. Untuk keadaan unggul bagi pengukuran 200 m menunjukkan maksimum pencapaian kadar bit pada VDSL2 ialah 29 Mbps bagi hulu dan 79 Mbps bagi hilir data dan anggaran kelajuan pada teknologi G.fast untuk pasangan tunggal ialah 662.5 Mbps. Keputusan pengukuran dan simulasi menunjukkan persetujuan yang sangat baik antara satu sama lain. Oleh sebab berlakunya kerosakan, prestasi rangkaian dari segi memaksimumkan pencapaian kadar bit dan prestasi kelajuan adalah menurun. Ini menunjukkan penurunan yang sangat teruk untuk kes kerosakan silang pepejal (SCF) dan kerosakan terbuka lengkap dan silang (COC) apabila dibandingkan dengan keadaan unggul. Pengukuran COC menunjukkan hulu data dan hilir data adalah rendah pada 38% dan 44% setiap satu apabila dibandingkan dengan hasil keputusan keadaan unggul. Hasil kajian menunjukkan disebabkan kerosakan kecil boleh memberi kesan terhadap prestasi rangkaian talian penghantaran berdasarkan hasil keputusan maksimum pencapaian kadar bit.

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LIST OF SYMBOLS AND ABBREVIATIONS

γ	-	Propagation
l	-	Length
α	-	Alpha
β	-	Beta
R	-	Resistance
P_o	-	Power out
P_i	-	Power in
Z_c	-	Characteristic Impedance
dB	-	Decibel
cm	-	Centimeter
m	-	Milli
mm	-	Millimeter
km	-	Kilometer
Mb/s	-	Megabit per second
MS/m	-	Megasiemens per meter
Gb/s	-	Gigabit per second
kHz	-	Kilohertz
MHz	-	Megahertz
3-D	-	Three Dimensions
ADSL	-	Asymmetrical Digital Subscriber Line
Al	-	Aluminium
CAT3e	-	Category 3 (Unshielded twisted pair cable)
Cat5e	-	Category 5 cable (Twisted pair cable for computer network)
Cat6	-	Category 6 cable (Twisted pair cable for Ethernet)
CO	-	Complete Open
COC	-	Complete Open and Cross

COS	-	Complete Open and Short
COG	-	Complete Open and Ground
CST	-	Computer Simulation Technology software
CST MW	-	CST Microwave Studio
CST CS	-	CST Cable Studio
DMT	-	Discrete Multi-Tone
DSL	-	Digital Subscriber Line
FDH	-	Fiber Distribution Hub
FTTC	-	Fiber to the cabinet
FTTH	-	Fiber to the home
FTTP	-	Fiber to the Premises
FTTDP	-	Fiber to the distribution point
G.fast	-	Fast Access to Subscriber Terminal
HDSL	-	High Bit Rate Digital Subscriber Line
ITU	-	International Telecommunication Union
LVURD	-	Low Voltage Underground Cable
MATLAB	-	Matrix Laboratory Software
PLC	-	Power Line Communication
PE	-	Polyethylene
PO	-	Partial Open
POS	-	Partial Open and Short
POG	-	Partial Open and Ground
RLCG	-	Resistance, Inductance, Capacitance, Conductance
SGF	-	Solid Ground Faults
SCF	-	Solid Cross Faults
SNR	-	Signal to noise ratio
Streamyx	-	Broadband Services
TDR	-	Time Domain Reflectometry
TL	-	Transmission Lines
TNO	-	The Netherlands Organisations
UY2	-	Solvent Resistant Connector
Unifi	-	Internet Service Provider in Malaysia
VDSL2	-	Very High Speed Digital Subscriber Line 2
VNA	-	Vector Network Analyzer

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the late 20th century, digital subscriber line (DSL) technologies had begun flourishing, along with the boom of digital technologies. It was the era that witnessed the advent of integrated services digital network (ISDN), as well as symmetrical high-speed DSL (SHDSL), asymmetrical DSL (ADSL), and very high-speed DSL (VDSL) series technologies, for residential services including video on demand (VoD), internet access, and Internet Protocol Television (IPTV) [1]. The evolution of DSL technology led to dual primary drawbacks in service provider, namely provision of higher bandwidth, and increment of effective coverage area of broadband services, for both residential and business premises [2]. The technology of VDSL transceivers 2 (VDSL2) that derived from ITU-T standard, which refers to G993.2, is deployed worldwide. This technology has introduced a hybrid copper-fibre solution that enables the copper cable to deliver achievable bit rate up to 100 Mbps via short copper loops.

In 2008, the Malaysian government signed a Public Private Partnership (PPP) agreement with Telekom Malaysia Berhad (TM) to roll out high-speed broadband (HSBB) infrastructure at selected regions [3]. At present, TM provides VDSL2, which refers to HSBB, across high-impact areas with speed up to 100 Mbps through its HSBB project. Besides, the Sub-Urban Broadband (SUBB) project is targeted to provide broadband in rural areas with speed up to 20 Mbps [4]. This makes G.fast technology an exceptional option [5]. The upgrading of DSL using twisted pair of copper cable demands high data rates to support an array of high-speed applications. This sparked the development of the fourth generation broadband (4GBB) technology, known as “Fast access to subscriber terminals” or “G.fast” due to vectoring of the VDSL2 technology in a single line performance that can be attained when re-establishing the limiting factor of loop length [6].

The optical fibre technology to date has an extended reach due to its inherent low attenuation and it is ideal to send high data rates over long distances. Fibre to the home (FTTH) is the ultimate upgrade in broadband access. Nevertheless, a direct transition of FTTH connectivity can be hampered by enormous capital expenditures and lengthy roll-out time required to build these networks [7].

A number of techno-economic investment evaluations have revealed that the deployment of FTTH can be justified insufficiently across urban areas. The FTTdp refers to a broadband access solution by taking fibre to a distribution point unit (DPU) very close to premises of clients, with the total copper wire length to customer premises equipment (CPE) being up to 250 m [8], while VDSL2 with Fibre to the node (FTTN) can go up to 800 m using an operator access system called DSL Access Multiplexer (DSLAM). Copper cables are still applied from cabinet to DPU, as illustrated in Figure 1.1. Nonetheless, TM had substituted copper cables with fibre optic cables from central office to cabinet street.

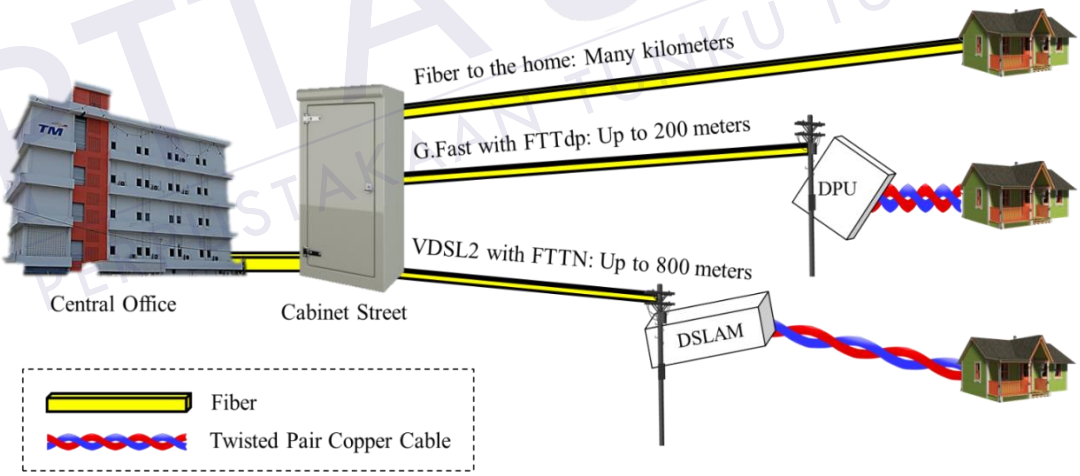

Figure 1.1: Phone system cabling

The implementation of National Fiberisation and Connectivity Plan (NFCP) by TM has gained support from the government by utilising the existing funding to deliver better broadband services to rural and sub-urban regions, so as to resolve Streamyx and Unifi issues that launch on April 2001, including complaints of high prices and lack of high-speed internet connectivity. The Streamyx service refers to a broadband service based on copper network, whereas the Unifi service is only available at certain fibre optic areas. The NFCP plan is the way forward to address not only the shortcomings of the copper broadband network, but also to lay the foundation for better internet experience for all customers nationwide in 2021 [9]. In providing nationwide roll-out of broadband services while gradually transitioning to FTTH network, telephone network operators have begun leveraging hybrid fibre-copper architectures, collectively dubbed as FTTx. These FTTx solutions include fibre-to-the-cabinet (FTTC) with vectored VDSL2 and fibre-to-the distribution-point (FTTdp) with G.fast. Limiting the copper loop with each subsequent technology innovation generates more spectra, along with new challenges for deployment. The G.fast standard is optimised for copper loops up to 250 with 106 MHz bandwidth and maximum aggregate data rate that approaches 1 Gb/s [10].

Upon upgrading many cabling systems into fibre optic cable, such as FTTH, the copper cable can still reach most users, particularly those residing in rural area. The achievable capacity for copper cable is influenced by attenuation, which can be represented as an interconnected lump element in resistance, inductance, capacitance, and conductance (RLCG). Hence, it is essential for service providers to estimate performance speed based on insertion loss and details that embed transmission lines (TLs) model RLCG [11].

The environment, however, may cause common copper cable faults, such as cable bleeding. Cable bleeding that leads to severe attenuation adversely affects the performance of access network. This impact helps to explain the customers’ side.

In this project, several pairs of CAT3 copper TLs model were simulated to observe their performances in terms of signal attenuation in both ideal and non-ideal cases, which refers to configuration faults in cable bleeding. A series of laboratory tests was conducted to generate the real setup case that typically occurs in the field location. This project emulated the likely defect condition via laboratory tests and measurements. This work sought the real causes that take place in the field, regardless of environmental effect or human factor. Both simulation and measurement outcomes were compared to verify the assumptions made in order to validate the results.

1.2 Problem statement

Telekom Malaysia (TM) has targeted to achieve broadband services maximum achievable bit rate at 100 Mb/s using VDSL2 technology between 0 MHz and 30 MHz and in future generation access at 1 Gb/s for G.fast technology up to 106 MHz. Unfortunately, cable bleeding has affected the quality of copper cable in transmission network stemming from poor performance. Further probe into the faults revealed that the realisation of speed at 100 Mbps for VDSL2 demands an elaborated study to avoid degradation of maximum achievable bit rate.

A comprehensive study that looks into the impact of cable bleeding on 3D modelling is absent. Speaking of methodology, numerous studies have employed the Time Domain Reflectometry (TDR) to detect copper cable faults by figuring out the distance of faults in cable. Nevertheless, the details of the type of cable bleeding seem to be omitted, particularly pertaining to the effect of cable bleeding that contributes to a number of factors that dictates network performance. Although several types of cable bleeding are detectable, no study has comprehensively assessed cable bleeding from the stance of resistance and capacitance faults.

Addressing the intricacies in several 3D modelling of fault cable that initiate the presence of water by using Computer Simulation Technology Microwave (CST MW) software is the initial contribution of this project. All 3D modelling for resistance and capacitance faults were integrated into the CST Cable Studio (CST CS) software for further investigation on long distance cable. The second contribution of this project is revelation of the performance with cable bleeding impact in several ideal cases of maximum achievable bit rate or speed rate.

The simulation results were compared with those of measurement. This comparison enlightens the correlations between faults and the impact of cable bleeding cases, in which some turned to be insignificant. The configurations of faults cable impact were identified in this project due to the vast possibilities of faults in copper cable. It is integral to determine the speed of copper cable based on cable distances and other possible effects of cable bleeding.

1.3 Objectives

The objectives of this project are outlined in the following:

i. To investigate performance degradation of copper cable due to cable bleeding
ii. To correlate the impact of cable bleeding with various configurations of resistance and capacitance faults
iii. To validate the simulation and measurement results of fault in copper cable with various configurations

1.4 Scopes

The scope of this project is narrowed to the following three major components:

i. The resistance faults only covered solid ground faults (SGF) and solid cross faults (SCF).
ii. The capacitance faults only covered split, complete open, complete open with combination faults (cross, short, and ground), partial open, and partial open with combination faults (short and ground).
iii. The frequency operation for both simulation and measurement ranged from 0 MHz to 30 Mhz for VDSL2, and up to 106 MHz for G.fast technology.
iv. The simulation modelling for 3D cable faults is expressed into CST MW Simulation Software.
v. The integration of 3D simulation modelling into long distance cable from 100 m to 800 m was investigated in CST CS software.
vi. The cable bleeding part for both measurement and simulation in copper cable was 3 mm.
vii. The simulation water size was modelled with $1.2 \times 1.4 \times 3.4$ mm^3 in a rectangular shape with 5.712 mm^3 volume at each presence of water design simulation.
viii. The experimental works were performed by using 10 pairs of CAT3 copper cable in Malaysia.

ix. The limitation measurement and simulation distance cable for ideal case is from 100 m to 800 m and for fault cases up to 200 m only.

x. The two selected configurations of cable faults were cable bleeding with resistance and capacitance faults.

xi. Measurement and simulation performances based on the attenuation results were referred to VDSL2 and G.fast technology.

xii. The attenuation results portrayed the RLCG model and the performance maximum achievable bit rate was assessed using MATLAB.

1.5 Thesis Organisation

This thesis looked into the impact of cable bleeding on performances displayed by VDSL2 and G.fast network technologies. The following chapter, Chapter 2, introduces the architecture of the copper access network. Next, the generation background of the evolution of DSL from xDSL to G.fast technology is elaborated in detail. The TL model for the communication framework is described in equivalent circuit. The identified physical cable faults and their impacts are represented in a schematic diagram. The last section in Chapter 2 focuses on other related simulation software applications, and how this work is distinguished from other investigations.

Chapter 3 provides a brief description of the research work, particularly the simulation software and the measurement technique in validating the thesis statement. Next, a 3D modelling is illustrated based on the standard parameter used in Malaysia's copper cable CAT3 derived from TM. The modelling cable was classified into two cable faults; resistance and capacitance faults. By using the modelling fault cable, measurement was performed to validate the simulation outcomes via vector network analyzer (VNA).

In Chapter 4, the performance studies were extended to point-to-point analysis in order to determine the performance of copper cable that ranged between 100 m and 800 m distance cable based on the attenuation outcomes. Both simulation and experimental studies were carried out on two conditions; ideal and non-ideal cases, such as cable bleeding in faulty cable. After that, the attenuation results were integrated into RLCG model to identify the limiting factor for the performance of G.fast technology distance below 300 m cable.

Lastly, Chapter 5 summarises this study and paves the path for future work. The final statement highlighted in this chapter highlights the implementation of VDSL2 in Malaysia, along with the deployment of G.fast technology, so as to satisfy the requirement stipulated in standard ITU–T G 9.700.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, detailed description about the architecture of copper access network is provided starting from the central office until the premises of users. Primarily, this chapter looks into the DSL technology, which is closely linked with this particular project. The physical faults cable and their classifications are presented in schematics. Next, a number of reflectometry methods for localisation cable faults are compared. Lastly, the advantages and drawbacks of other related research work pertaining to fault cable via cable modelling end this chapter.

2.2 General background of DSL

The DSL, also known as ‘local loop’, refers to a digital broadband technology that transmits digital information to a subscriber’s line [12]. From the wide range of available DSL technologies, the xDSL technology has been reckoned for its speed and application. The prefix ‘x’ in xDSL technology indicates placeholder, which is similar to H in HDSL that denotes high speed mostly used by business subscribers, while A in ADSL signifies asymmetrical typically applied by residential consumers. Figure 2.1 illustrates the evolution concerning access speed over copper.

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